

# Miniature Neural Interface Microdrive using Parylene-coated Layered Manufacturing\*

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**Abstract** –This paper describes a prototype neural interface “microdrive” capable of positioning electrodes with micron precision to record signals from active neurons. The prototype is part of ongoing efforts to develop “smart” neural implant devices that can autonomously optimize neural signals for long-term recordings. Such implants will enable new generations of neural prosthetic systems that will allow patients with lost motor function to control external devices through thoughts alone. The prototype presented was constructed using a layered manufacturing (rapid prototyping) method and made bio-compatible through coating of Parylene. The microdrive offers several advantages over much of the current state of the art in neural recording devices and can be used to support studies in both neural prosthetics and general neurophysiology. A companion paper describes the algorithm used to control the device for autonomous operation.

**Index Terms** – Neural Prosthetics, Neural Interfaces.

## I. INTRODUCTION

The ability to interact directly with the nervous system to control a computer cursor or robot arm has recently been demonstrated by several researchers [1]-[5]. These advances in neural prosthetic systems may one day allow patients with lost motor function due to spinal cord injury, stroke or neurodegenerative diseases the ability to regain access to their surroundings. Despite these recent breakthroughs, however, many challenges remain [6]. A fundamental problem lies in creating interface devices capable of sustaining interaction with neuronal populations for long periods of time in a practical and reliable manner. Long-term neural interfacing demands that the overall device be implantable, safe, minimally obtrusive and requiring of minimal maintenance.

One of the challenges lies in placing electrodes close enough to active neurons to discriminate their electrical activity. Implantation of simple electrode arrays that cannot be re-positioned depend on the luck of the initial implantation surgery to achieve this. Moreover, neurons close enough to the recording electrode may not encode the proper task for the prosthetic system, rendering that

electrode useless. Even if the right signal is obtained, small tissue migrations, inflammation, cell expiration or reactive gliosis can all cause the signal to be lost over time.

To solve this problem, we have proposed the development of “smart” neural recording implant devices, that is, robotic microdevices that can autonomously and individually position arrays of electrodes within neural tissue to seek out and continuously optimize signals from neurons [7]. Such autonomously controlled electrodes would have the ability to break out of encapsulation tissue, or move on to other areas to seek better signals. Previous work has described initial mesoscale versions of such robotic devices meant for autonomous semi-chronic operation [7], while current work aims to apply MEMS technology to create arrays of multi-site electrodes motorized by hydrolysis-based actuators [5].

Our experience in this area has emphasized another difficult challenge in the development of implantable neural interfaces. Creating mechanisms and devices for small bio-robotic devices poses design and manufacturing challenges that strain the capabilities of traditional manufacturing processes even at the mesoscale level. Traditional manufacturing techniques rely on assemblies of pre-manufactured parts and fasteners that can compromise

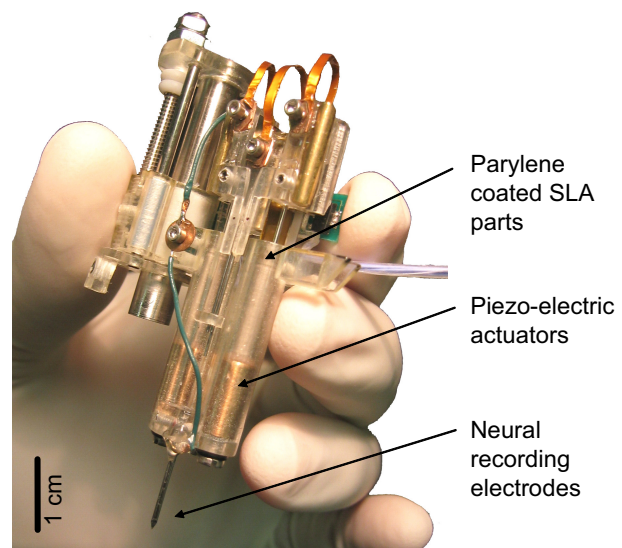


Figure 1. Prototype miniature neural recording microdrive. The device is capable of positioning three sharpened electrodes with micron precision to optimize signals from active neurons, and was created from parts made with stereolithography (SLA) and coated with Parylene.

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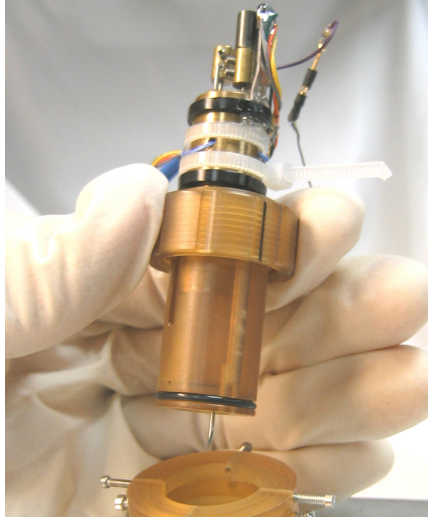


Figure 2. Previous prototype [7]. This prototype was constructed using traditional manufacturing methods.

the reliability of the device. Fasteners and connectors not only take up a large percentage of the design volume at small scales, but can often work themselves loose or give way to leaks in the wet conditions of living tissue.

Non-traditional manufacturing techniques such as layered manufacturing, in which parts and mechanisms are “grown” in layers, allow intricate structures to be made with nearly arbitrary geometry and few seams [8][9]. Many of these processes, however, are limited by the bio-incompatibility of the materials available through these processes.

In this paper, we describe the design and manufacturing of a novel prototype mesoscale semi-chronic neural recording robotic microdrive, shown in Figure 1. The design incorporates lessons learned from previous prototypes, and is shown capable of advancing three electrodes to simultaneously record from multiple neurons in brain cortex. The prototype body was manufactured through a layered manufacturing process, in this case stereolithography, which is commercially available at a relatively small cost. The manufactured parts were made biocompatible by coating them with Parylene, a conformal plastic known for its excellent biocompatibility properties.

In the next sections, we describe the prototype’s design and manufacturing in the context of previous work and the requirements of implantable devices for neural recording. Efforts to develop a fully autonomous algorithm for the control of actuated recording devices such as the one presented here are described in a companion paper [10].

## II. DESIGN

### A. Background: Neural Recordings

Signals are recorded from neurons in one of two general ways: acute and chronic recording methods. In acute recordings (sessions typically lasting several hours), individual electrodes are advanced into tissue at the beginning of each day through a cranial chamber (an

implanted structure that allows access through the skull; see bottom of Figure 3). Commonly, the electrodes are advanced via human control of devices termed microdrives, until high quality neural activity is perceived, after which readjustment is often required to re-optimize and maintain signal quality. This procedure often consumes a large percentage of the experimentalist’s time, and it becomes nearly impossible to track individual neurons across multiple sessions.

In chronic recordings, multi-electrode bundles or arrays of stationary thin wires or silicon probes are surgically implanted in the region of interest (for example, [11][12][13]). As previously mentioned, such arrays are limited in their flexibility for long-term recording. The percentage of electrodes that are close enough to active neurons useful to the task depends on chance, and many factors can contribute to disabling the electrodes (tissue reaction or movement, cell expiration, etc).

A solution to the limitations of both methods is a microdrive small enough to be implanted chronically. Commercially available drives (for example: Thomas Recording GmbH, Germany; FHC Inc., USA; Narishige Inc., Japan) are too large to be practical for chronic use. While chronic microdrives have been reported by several investigators [14]-[20], these devices commonly require manual intervention to reposition electrodes, such as turning lead screws or interfacing with a conventional microdrive. Even if they are motorized, chronic microdrives still face the challenge of requiring constant human supervision to adjust the electrodes to achieve optimal signals. This process can become tedious and even impractical as the number of electrodes increases [21].

Currently, efforts are underway to develop large arrays of individually actuated micro-electrodes using MEMS technology [5]. Until this technology matures, our work has focused on creating mesoscale prototype microdrives that utilize current miniature actuator technology as a bridge to smaller devices meant for chronic use. These “semi-chronic” prototypes (capable of acute use or of continuous use for periods of several days or weeks) are enabling us to explore strategies for long-term, fully-autonomous recording with movable electrodes, as well as to characterize tissue reaction and coupling.

The prototype presented in this paper is the next iteration of the design presented in [7], shown in Figure 2. Several improvements have been made to increase its performance and reliability and, most notably, its ease of use and reuse. The following sub-section describes the design in more detail.

### B. Design Challenges and Description

The central challenges in designing a semi-chronic microdrive is in maintaining a small size and mass, securing the device against leaks and impacts, and maintaining its ease of use for the experimentalist. The device must be capable of being installed while allowing the subject free movement and comfort without risk of injury.

The size and mass restrictions result in many challenges in the design of the device. The size requirement limits the number of actuators that can be packaged in the device, and the compactness and proximity of all the electrical pathways increases noise and interference in the recording signal.

The basic design of the prototype is shown in Figure 3. The microdrive's central structure is the main body, which encases three piezo-electric linear actuators and furnishes mountings for the electrode guide tube and circuit board. The piezo-electric actuators (Klocke Nanotechnik, Germany) provide simultaneous high-precision (sub-micron steps) and long range of motion (about 5.6 millimeters) and do not suffer from gear backlash. This movement is sufficient to track neurons within a reasonable range of cortical locations. Hall-effect sensors incorporated into the small mounted circuit board provide knowledge of electrode depth to 1 micron precision. This is particularly important when the electrode position is to be computer-controlled.

The linear actuators move independent "carriers" at the top of the drive to which the electrodes are attached both electrically and mechanically. The electrodes consist of platinum-iridium wires coated with glass along their length (except at the recording tip and the back end) for electrical insulation (Alpha Omega Co., USA). The signals from the electrode are then routed to the circuit board via flexible, polyimide-shielded copper strips, and then routed to a standard multi-pin connector that connects to a headstage amplifier.

The body assembly is held to a chamber adapter via a main shaft (see Figure 3). The design allows the main body to be positioned over a range of locations within the chamber, giving the experimentalist the flexibility to deploy the electrodes over multiple brain areas. Rotation of the body assembly around the main shaft axis combined with rotation of the chamber adapter on the chamber rim sets the guide tubes and the electrodes over any location within a 12mm diameter circular area inside the chamber.

After setting the desired planar position within the chamber, the microdrive is lowered by manual turning of the vertical lead screw. This is done until the guide tube just pierces the dura, which is the tough layer of tissue protecting the brain. Our custom guide tube – consisting of three stainless steel pieces of hypodermic tubing, honed together to a sharp point – protects the fragile electrodes (see Figure 4c). This gross vertical lowering of the guide tube is critical and can be challenging, as it is often difficult to tell when the dura has been pierced and lowering the guide tube too much can damage brain tissue. To this end, the prototype was designed to maximize visual and tactile feedback during this operation. The design allows the experimentalist a rough view of the point of insertion and includes clear vertical markings that show insertion depth. Teflon bearings were used to minimize friction and increase the movement's smoothness.

Once the guide tube is in the correct position above the brain, the electrodes are deployed by activating the piezo-electric actuators. For semi-chronic use, structural

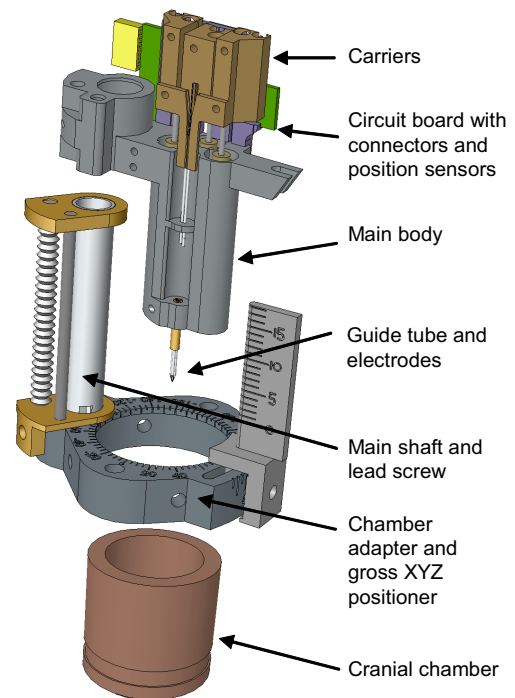


Figure 3. Design of the new prototype microdrive. The chamber adapter is fitted over a standard recording chamber, which is implanted in the skull. The adapter provides mechanisms for gross adjustment of the device in the horizontal and vertical directions. The main body of the drive is fitted on the main shaft of the adapter and is lowered by manual turning of the lead screw.

elements are locked into place with set screws, and a cover can be placed over the entire assembly for protection against impact and fiddling by the subject.

Finally, a critical challenge is in making the device flexible to experimenter's needs. For example, the microdrive must be adjustable for different subjects, cranial chamber locations, and in situ conditions. The microdrive must be sufficiently easy to use and maintain, contributing to experiment practicality and device longevity. In this design, cleaning and maintaining the microdrive as well as loading new electrodes were made as simple as possible. New electrodes are loaded by simply feeding them tail-first (to avoid damage to the tip) through the guide tube and their corresponding carrier tubes, and fixing them under screw heads on the carriers, which supply both the mechanical and electrical connections to the microdrive. Since there are no parts to disassemble between uses, cleaning is accomplished by a simple bath in a disinfectant solution such as hydrogen peroxide.

### III. MANUFACTURING

In looking at ways to manufacture the design described above, the difficulties in building small, implantable bio-robotic devices with movable parts became apparent. Implanted "smart" devices must be of minimal size and maximum reliability and durability. At small scales, traditional methods of manufacturing, which rely on machining and assembling individual parts, lose a lot of space in providing enough material for fasteners,



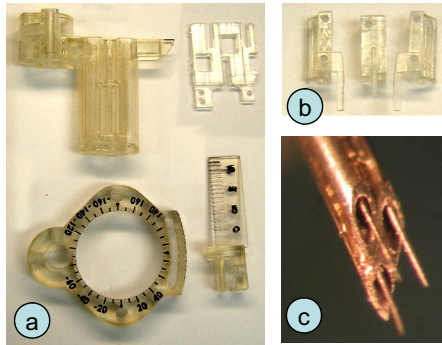


Figure 4. Manufacture of the prototype microdrive. a-b) Parts made with SLA and coated with Parylene. c) Electrodes protrude from a protective guide tube, which consists of three sharpened hypodermic tubing lengths.

connectors and sealing, resulting in bulkier devices. This approach also compromises long term reliability, as fasteners can work themselves loose and seals can leak over time. Even if the central components are made using MEMS technology, these must be housed and connected through an overall structure that also faces the same difficult conditions.

Recently, the use of layered manufacturing technologies has been proposed to create functional robotic devices [9]. In layered manufacturing, parts are not machined and assembled, but rather build up in layers by the repeated deposition of material unto a substrate. These processes allow parts to be created with nearly arbitrary geometry in relatively short amounts of time. Layered manufacturing processes include rapid prototyping technologies such as stereolithography (SLA) and 3D printing. Another layered manufacturing technology with potential for these types of applications, Shape Deposition Manufacturing (SDM), would allow active components such as actuators and sensors to be embedded within solid structures through its unique cycle of alternating material deposition and removal [8][22][23]. Structures can be made that combine soft and hard materials in ways that mimic the elegant structures seen in nature.

These processes offer an alternative solution to the construction of small bio-robotic devices. One advantage is the ability to create compact designs that are not encumbered by fasteners or connectors or that require additional sealing between assembled components. Structures with complex geometry that would be impossible to make with traditional methods can be made as one solid piece. Other advantages include the relatively short time between design iterations and the ability to custom-modify each device to fit a particular patient or implantation site with relative ease.

One constraint, however, is that the materials used in these processes are often not bio-compatible. In the work presented here, we take the additional step of coating the parts made by SLA with Parylene. Parylene is the generic name for a family of thermoplastic polymers that can be deposited using room-temperature low pressure chemical vapor deposition (LPCVD). Parylene is known to be biocompatible (it is a US Pharmacy class-VI implantable

material), and is commonly used for coating of biomedical devices such as pacemakers. Recently, its potential in creating MEMS neural probes and flexible connectors has been explored [24].

The design described in the previous section was manufactured using a low-cost SLA process, which allows for layer thicknesses of 0.1mm. A thin film of 20 microns of Parylene was coated on the parts using a commercial LPCVD machine (Part number SCS PDS2010E Labcoter). Sample parts are shown in Figure 4a-b.

Certain steps were taken to account for the limitations in precision of the SLA process. Because of the finite beam size of the computer-controlled laser that solidified the layers of the UV-curable plastic used in the process, actual dimensions varied approximately 0.1mm from the specified value. These variations, however, as well as the thickness of the Parylene coating, were found to be relatively consistent, and were accounted for in dimensioning the model.

These variations posed a problem for the slider and turn screw mechanism for gross XYZ adjustment of the microdrive. In this case, variations in the slider joint would cause play in the movement of the drive, which would cause damage to the tissue when inserting the guide tube through the dura. To this end, these joints were design with Teflon bearing inserts whose fit could be adjusted with small set-screws to achieve the right amount of joint precision and smoothness needed when advancing the guide tube.

Finally, the geometry of the parts was designed such that areas of high stress were reinforced to account for the flexibility of the SLA plastic (available plastics for SLA have mechanical properties that approximate ABS plastic).

The parts were manufactured in 2 days at a cost of approximately \$250 USD. The Parylene coating was completed in one day, and assembly of the parts was completed in approximately 2-3 days. The final assembled prototype is shown in Figure 4d, and weighs 26.1g.

#### IV. RESULTS

Figure 5 shows neural data recorded simultaneously through the microdrive's three electrodes. Graphs in column (a) plot several seconds of the filtered data stream over time, sampled at 20 kHz, with blue dots above the voltage trace at times when spikes (neuron action potentials) were detected. Column (b) shows close-up views of these detected spikes with their minimum voltage aligned at 0 ms. The spikes are underlaid by noise samples (in gray).

The diagram on the right side of the figure indicates the relative depths of the three electrodes at the time of the recordings. Sample action potentials recorded in consecutive positions of electrode 3 are also shown near the depths at which they were recorded.

While the quality of the recorded signal and ability to autonomously position the electrodes with high precision are comparable to the previous prototype [7], experimenters report significant improvements in the drive's usability and flexibility:

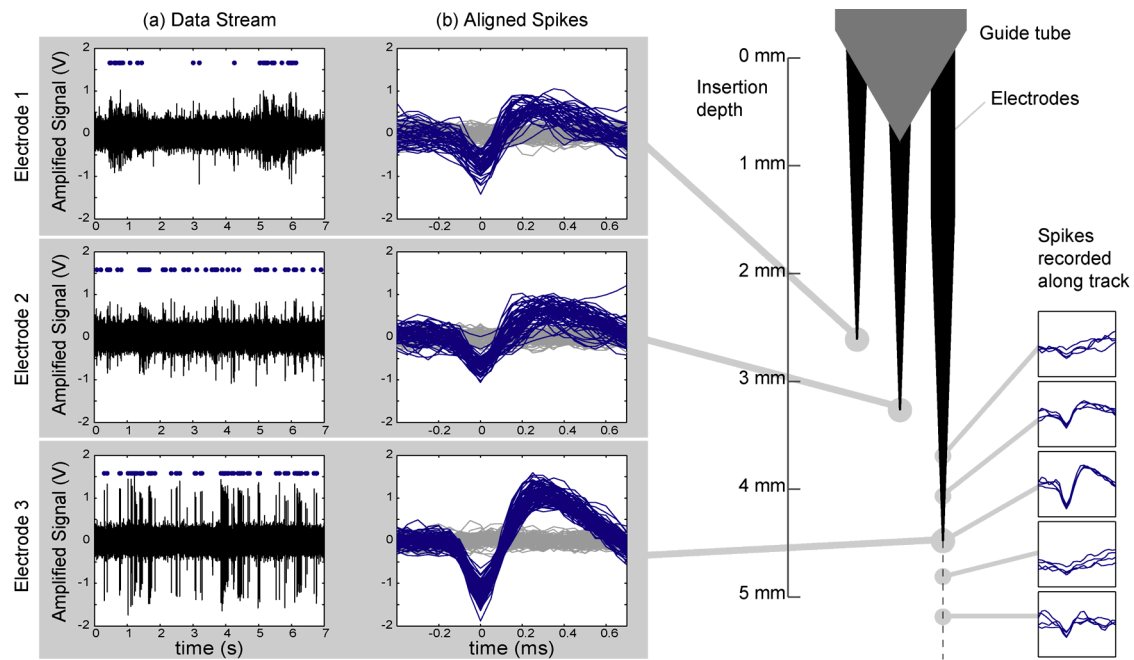


Figure 5. Simultaneous recording of neurons using the prototype microdrive. Column a) shows the raw filtered data stream. Column b) shows the detected and aligned spikes. The diagram on right shows to relative scale the positions of the electrodes when the recording was made, as well as sample spikes recorded along the trajectory of electrode 3.

- The new prototype's design reduced electrode loading and device cleanup time by more than half, owing to the accessibility and lack of assembly required of key components.
- The design greatly increases ease and reliability of dura penetration, due to the improved visual and tactile feedback during insertion and the redesigned guide tube.
- The use of SLA parts increased robustness to breakage and leakage of biological fluids, and made the microdrive components easier to repair, replace and also revise.
- The new design reduced the total weight by nearly half from the previous design, primarily due to the elimination of metal modules and fasteners.

These improvements in usability are critical because the success of any microdrive will depend on the ease with which experimenters can adopt the device into their experimental procedure.

An important question we also addressed was the extent to which the electrodes interfere with each other when moving. For example, will repositioning one electrode shift the tissue around the other electrodes and inadvertently alter their signals? This scenario has been known to occur, though it appears to be dependent on the dimensions of electrodes (and their spacing).

The data shown in Figure 6 represents an initial experiment aimed at investigating whether this issue occurs in our microdrive. In the experiment, the position of electrodes 1 and 2 were held constant, each close to an active neuron. Electrode 3 was then moved back and forth (at a speed of 6  $\mu\text{m/s}$ ) and data streams were recorded on all three channels at each position.

First, we should note electrode 3's movement caused no change in the position of electrodes 1 and 2, as verified by the microdrive's position sensors. Next, we infer effects on the fixed electrodes' signals by looking for correlation between their signal-to-noise ratios (SNRs) and electrode 3's position. From visual inspection of the figure, no clear relationship between the signal metric and electrode 3's position seems apparent. Only a general downward trend is observed in the signal quality, which does not correspond to electrode 3's up and down motion.

This downward trend in the two fixed electrodes' SNRs over the time period may be explained by gross tissue movement (e.g. relaxation following initial electrode advance). The trend is consistent with the frequently observed loss of signal quality due to tissue migration in acute experiments [7]. While further investigation is required to conclusively rule out coupling between the electrodes, these initial results suggest that it is not a significant issue for the electrode separation in our prototype (the centerlines of the electrodes are about 400 microns apart).

## V. CONCLUSIONS AND FUTURE WORK

In this paper we have described current efforts to develop "smart" neural implant devices capable of autonomously positioning recording electrodes to seek out and optimize signals from active neurons. While the full realization of the dream will await further advances in MEMS technology, much can be learned and accomplished at the mesoscale level, where current miniature actuator technology can be used. Thus, we have developed a series of small-scale microdrives using available technology to use as test-beds for exploring the

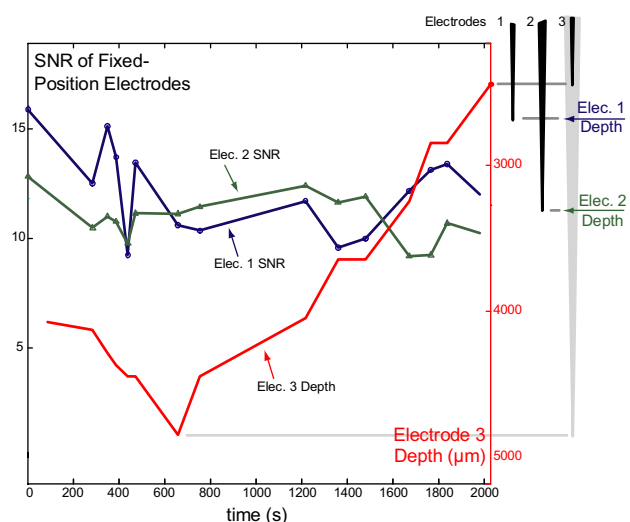


Figure 6. Signal-to-noise ratio (SNR) recorded from electrodes 1 and 2 along with the position of electrode 3. The SNRs use the left y-axis, while the right y-axis indicates the depth of electrode 3.

autonomous control of recording electrodes and its impact on brain tissue and long term recording. The prototype presented in this paper is meant to be used both acutely and semi-chronically and takes into consideration both performance and ease-of-use factors in its design. In addition to its role as a test-bed for future development, the device offers several advantages over much of the current state of the art in neural recording devices and can be used to support neurophysiological studies.

The prototype was constructed using a Layered Manufacturing process (in this case, SLA), and made bio-compatible through a coating of the thin-film polymer Parylene. This method for creating rapidly manufactured, bio-compatible parts of complex geometry provides a useful alternative in the design and manufacture of bio-robotic devices in general. Such alternative techniques can result in smaller, more robust devices that can potentially be customized to the implantation site on a per-patient basis.

Future work will address issues in long-term recording with movable electrodes, such as characterizing tissue reaction to continually moving electrodes. Concurrent work focuses on the algorithmic challenges in fully automating electrode movement to optimize neural signals [10], and is described in a companion paper. Combined with advances in hardware and actuator technology, such systems will make possible the development of future brain controlled neural prosthetics.

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